Neutralino spin measurement with ATLAS

A. Ventura for the ATLAS collaboration*
INFN, Sezione di Lecce, Via per Arnesano, I-73100 Lecce, Italy

Abstract
One of the goals of the ATLAS experiment at the LHC is to search for evidence of Supersymmetry (SUSY) signals and to measure, if discovered, the main properties of the new particles, like the spin. Left-handed squark cascade decay to second lightest neutralino ($\tilde{\chi}_2^0$) which further decays to slepton represents a good opportunity for SUSY particles' spin measurement. The observability of charge asymmetries in invariant mass distributions of some final products is investigated to prove that neutralino spin is 1/2. The criteria used to select signal events and to reject background are described, together with the applied cut efficiencies. Results on charge asymmetry are then shown and discussed.

1 Introduction

The Minimal Supersymmetric extension of the Standard Model (MSSM) [1] is a promising candidate to describe the physics beyond the Standard Model. The minimal Supergravity (mSUGRA) breaking mechanism is assumed here. After a possible discovery of physics beyond the Standard Model (SM) at the LHC, it will be fundamental to measure properties of new particles, like spin, in order to prove that they are indeed SUSY partners. The present study [2] is based on a method [3] which allows to choose between different hypotheses for spin assignment, and to discriminate SUSY from an Universal Extra Dimensions (UED) model mimicking low energy SUSY [4, 5].

2 Spin measurement

The cascade decay of the $\tilde{q}_L$ to $\tilde{\chi}_2^0$ which further decays to slepton:

$$\tilde{q}_L \,\rightarrow\, \tilde{\chi}_2^0\, q \,\rightarrow\, \tilde{\ell}^{\pm}_{L,R}\, \ell^{\mp}\, q \,\rightarrow\, \ell^+\, \ell^-\, q\;\; \tilde{\chi}_1^0 \tag{1}$$

gives an excellent opportunity for measuring SUSY particles' spin [3]. In the following, the first lepton (from $\tilde{\chi}_2^0$ decay) is called *near*, and the one from slepton decay is called *far*.

In the MSSM, squarks and sleptons are spin-0 particles and their decays are spherically symmetric, differently from the $\tilde{\chi}_2^0$ which has spin 1/2. A charge asymmetry is expected in the invariant masses $m(q\ell^{near(\pm)})$ formed by the quark and the near lepton. Also $m(q\ell^{far})$ shows some small charge asymmetry [4, 5], but it is not always possible to distinguish experimentally near from far lepton, thus leading to dilution effects when measuring $m(q\ell^{near(\pm)})$ charge asymmetry.

In the cascade decay (1), the asymmetry in the corresponding $m(\bar{q}\ell)$ charge distributions is the same as the asymmetry in $m(q\ell)$ from $\tilde{q}_L$ decay, but with opposite sign [6]. Though it is not possible to distinguish q from $\bar{q}$ at a pp collider like the LHC more squarks than anti-squarks will be produced. In this work only electrons and muons are considered for analysis.

3 SUSY production and kinematics

Two mSUGRA points were selected for analysis: SU1 point, in the stau-coannihilation region (m_0= 70 GeV, $m_{1/2}$= 350 GeV, A_0=0 GeV, $tan\beta$=10, $sgn\mu$=+) and SU3 point, in the bulk region (m_0= 100 GeV,

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$m_{1/2}$= 300 GeV, A_0=-300 GeV, $tan\beta$=6, $sgn\mu$=+). In SU1 (SU3) LO cross section for all SUSY is 7.8 pb (19.3 pb).

In SU1 point, owing to the small mass difference between $\tilde{\chi}_2^0$ and $\tilde{\ell}_L$ (264 GeV and 255 GeV, respectively), the near lepton has low p_T in the $\tilde{\chi}_2^0 \to \tilde{\ell}_L \, \ell$ decay, while the small mass difference between $\tilde{\ell}_R$ and $\tilde{\chi}_1^0$ (155 GeV and 137 GeV, respectively), implies low values for far lepton's p_T in $\tilde{\chi}_2^0 \to \tilde{\ell}_R \, \ell$ decay. As a consequence, near and far leptons are distinguishable. Decay (1) represents $\sim 1.6\%$ of all SUSY production. From the three detectable particles ℓ^+, ℓ^-, q (where quark hadronizes to jet) in the final state of the $\tilde{q}_L$ decay (1) four invariant masses are formed: $m(\ell\ell)$, $m(q\ell\ell)$, $m(q\ell^{near})$ and $m(q\ell^{far})$. Their kinematic maxima are given by: $m(\ell\ell)^{max}$ = 56 GeV ($\tilde{\ell}_L$), 98 GeV ($\tilde{\ell}_R$), $m(q\ell\ell)^{max}$ = 614 GeV ($\tilde{\ell}_L$, $\tilde{\ell}_R$), $m(q\ell^{near})^{max}$ = 181 GeV ($\tilde{\ell}_L$), 583 GeV ($\tilde{\ell}_R$) and $m(q\ell^{far})^{max}$ = 329 GeV ($\tilde{\ell}_R$), 606 GeV ($\tilde{\ell}_L$). In the SU3 point, only the decay $\tilde{\chi}_2^0 \to \tilde{\ell}_R^{\pm} \ell^{\mp}$ is allowed (3.8% of all SUSY production). The endpoints for $m(\ell\ell)$, $m(q\ell\ell)$, $m(q\ell^{near})$ and $m(q\ell^{far})$ are 100, 503, 420 and 389 GeV, respectively.

Events were generated with HERWIG 6.505 [7]. SUSY samples corresponding to integrated luminosities of 100 fb^{-1} for SU1 and 30 fb^{-1} for SU3 were analysed. Also the most relevant SM processes have been also studied, i.e. $t\bar{t}$ + jets, W + jets, Z + jets produced with Alpgen 2.0.5 [8]. Events were passed through a parametrized simulation of ATLAS detector, ATLFAST [9].

4 Analysis

In this study [2] to separate SUSY signal from SM background these *preselection* cuts were applied:

- missing transverse energy $E_T^{miss} > 100$ GeV,
- 4 or more jets with transverse momentum $p_T(j_1) > 100$ GeV and $p_T(j_2, j_3, j_4) > 50$ GeV.
- exactly two SFOS leptons ($p_T^{lepton} > 6$ GeV for SU1, and $p_T^{lepton} > 10$ GeV for SU3).

At this selection stage, few invariant masses are formed: the dilepton invariant mass $m(\ell\ell)$, the lepton-lepton-jet invariant mass $m(j\ell\ell)$, and the lepton-jet invariant masses $m(j\ell^+)$ and $m(j\ell^-)$, where $\ell^{\pm}$ are the leptons and j is one of the two most energetic jets in the event. Subsequently

- $m(\ell\ell) < 100$ GeV, $m(j\ell\ell) < 615$ GeV (for SU1) or $m(j\ell\ell) < 500$ GeV (for SU3)

is required. In SU1, the decays (1) with $\tilde{\ell}_L$ or $\tilde{\ell}_R$ are distinguished asking for $m(\ell\ell) < 57$ GeV or $57 \; GeV < m(\ell\ell) < 100$ GeV, respectively. For SU1, in the decay (1) with $\tilde{\ell}_L$, the near (far) lepton is identified as the one with lower (higher) p_T, and vice versa for the decay (1) with $\tilde{\ell}_R$. Efficiencies and signal/background ratios after all the cuts described so far, when applied on SUSY and SM events, are shown in Table 1. Further background reduction is applied subtracting statistically in invariant mass

	Efficiency (SU1)	S/B (SU1)	Efficiency (SU3)	S/B (SU3)
Signal	(17.0 $\pm$ 0.3) %	/	(20.0 $\pm$ 0.3)%	/
SUSY Background	(0.94 $\pm$ 0.01)%	0.33	(0.75 $\pm$ 0.01)%	1
$t\bar{t}$	(2.69 $\pm$ 0.02) 10^{-4}	0.18	(3.14 $\pm$ 0.02) 10^{-4}	0.9
W	(1.4 $\pm$ 0.9) 10^{-5}	$\sim$16	(0.4 $\pm$ 0.4) 10^{-5}	$\sim$300
Z	(1.1 $\pm$ 0.3) 10^{-5}	$\sim$12	(0.9 $\pm$ 0.2) 10^{-5}	$\sim$100

Table 1: Efficiencies and S/B ratios for SUSY signal and background (SU1, SU3) and for SM background.

distributions events with two opposite flavor opposite sign (OFOS) leptons: $e^+e^- + \mu^+\mu^- - e^{\pm}\mu^{\mp}$ (SFOS-OFOS subtraction). This reduces SUSY background by about ~ 2 and makes SM events with uncorrelated leptons compatible with 0.

5 Results and background effects on asymmetries

Charge asymmetries of $m(j\ell)$ distributions have been computed after SFOS-OFOS subtraction in the ranges $[0, 220]$ GeV for SU1 (only for the decay (1) with $\tilde{\ell}_L$ and near lepton) and $[0, 420]$ GeV for SU3. Two methods have been applied to detect the presence of a non-zero charge asymmetry:

Analysed sample	SU1 selection			SU3 selection		
	CL_{χ^2}	CL_{RT}	CL_{comb}	CL_{χ^2}	CL_{RT}	CL_{comb}
a. SUSY SFOS-OFOS	19.1%	0.234%	0.390%	$4.22{\cdot}10^{-9}$	0.621%	$6.64{\cdot}10^{-10}$
b. SUSY OFOS	57.1%	92.1%	86.4%	19.3%	93.3%	48.9%
c. SUSY SFOS bkg	30.7%	24.0%	26.6%	53.5%	30.9%	46.2%
d. SM SFOS bkg	21.4%	24.0%	20.3%	61.3%	84.1%	85.7%
e. SM OFOS bkg	73.8%	50.0%	73.7%	95.5%	30.9%	65.5%
f. SUSY wrong jet	62.8%	50.0%	67.8%	19.7%	15.9%	14.0%

Table 2: Confidence levels for the two methods described in the text, separately and combined, obtained on $m(j\ell)$ distributions for the final selected samples and for various sources of background/systematics.

- a non parametric χ^2 test with respect to a costant 0 function, giving confidence level CL_{χ^2},
- a *Run Test* method [10] providing a confidence level CL_{RT} for the hypothesis of symmetry.

The two methods are independent and are not influenced by the actual shape of charge asymmetry. Their probabilities can be combined [10] providing a final confidence level CL_{comb}. In Fig. 1 charge asymmetries are reported for $m(j\ell^{near})_L$ in SU1 and for $m(j\ell)$ in SU3. With 100 fb^{-1}, in SU1 CL_{comb}

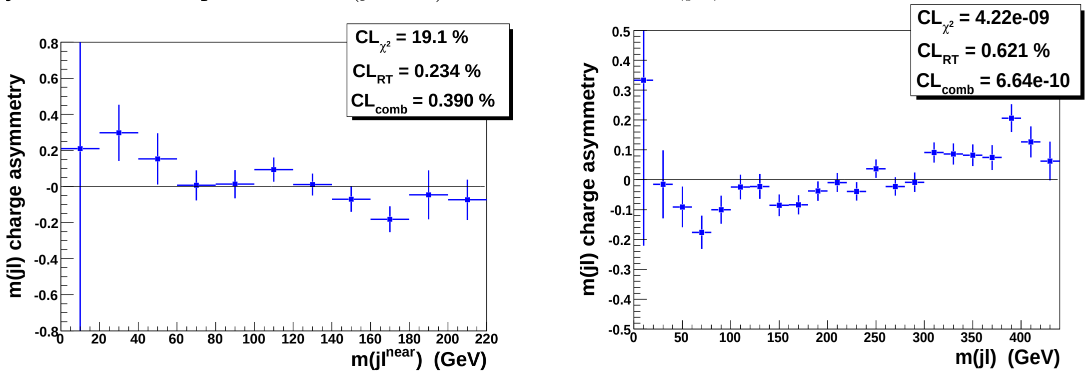

Fig. 1: Charge asymmetries for lepton-jet invariant masses after SFOS-OFOS subtraction. Left: using the near lepton from the chain involving $\tilde{\ell}_L$ in SU1 point. Right: using both near and far leptons in SU3 point.

is well below 1%, while for SU3 30 fb^{-1} are enough to get a CL_{comb} $\sim$$10^{-9}$. Different sources of background and possible systematic effects have been investigated [2] for SU1 and SU3 samples and the obtained confidence levels are reported in Table 2 (letters **b.** to **f.**), compared to the final SUSY selected sample (letter **a.**). They refer to: selected OFOS lepton pairs (**b.**), SFOS background SUSY events (**c.**), SFOS and OFOS selected SM background events (**d.** and **e.**, respectively) and events with $m(j\ell)$ formed with a wrong jet (**f.**). Anyway, confidence levels are much higher than the final selected SUSY sample.

It is observed that the evidence with a 99% confidence level for a charge asymmetry needs at least 100 fb^{-1} in the case of SU1, while even less than 10 fb^{-1} would be needed for SU3.

6 Conclusions

The decay chain $\tilde{q}_L \to \tilde{\chi}_2^0 q \to \tilde{\ell}^{\pm}_{L,R}\ell^{\mp}q \to \ell^+\ell^- q\tilde{\chi}_1^0$ has been studied [2] in two selected mSUGRA points to verify the hypothesis of the spin-0 slepton and spin-1/2 neutralino, by looking for charge asymmetry in invariant mass distributions. After describing selection and background reduction, two independent statistical methods have been used to detect the presence of charge asymmetry. Results show that at least 100 fb^{-1} is needed in the case of the SU1 point to observe a non-zero charge asymmetry with a confidence level of 99%, while in the case of the SU3 point 10 fb^{-1} would be sufficient.

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